Future propulsion technology made in Finland

CPT and Flex-CPT project outline

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Discipline Director - Energy Technology

Research Group Leader – Efficient Powertrain Solutions

June 2025

EFFICIENT POWERTRAIN SOLUTIONS

Vaasan yliopisto
UNIVERSITY OF VAASA

EPS

Efficient Powertrain Solutions

Prof. Maciej Mikulski

- 45+ research personnel
- 3 professors
- 8 post-docs (senior scientists/lecturers)
- 6 research/lab managers
- Engine and fuel testing laboratories (20 M€ net worth)
- 95% externally funded
- ~3 M€ annual research turnover

Vaasan yliopisto
UNIVERSITY OF VAASA

MISSION

- Efficient heavy-duty transport and energy sector
- towards zero/negative emissions impact

VISION

- We maximize overall powertrain energy efficiency while meeting emission limits under real-world operating conditions.
- We provide integrated powertrain control solutions …
- …and innovative tools for design optimization of powertrain configurations and control strategies

EPS Project Portfolio

Recently ended:

BF **CPT** (2020 – 2023); 15 Meu – PI

Eu **CHEK** (2021 – 2024); 12 Meu - PI

Running/Admitted:

BF **Silent Engine** (2022 – 2025); 3M€ – PI

BF **CASAMATE** (2022 – 2025); 3M€ – WP Lead

BF **DAZE** (2023 – 2026); 3M€ – WP Lead

BF **Flex-CPT** (2024 – 2027); 18M€ – PI

BF **iHAPC** (2025 – 2027); 10M€ – PI

BF **AINA** (2025 – 2027); 2M€ - WP Lead

Eu **4Blend** (2025 – 2027); 1M€ - WP Lead

Interested in details?
Let’s have a meeting!

Vaasan yliopisto
UNIVERSITY OF VAASA

Coordinated Powertrain Development in Finland

…to secure the global technology leader position for the Finnish powertrain industry by creating a common vision and sustainable business solutions.

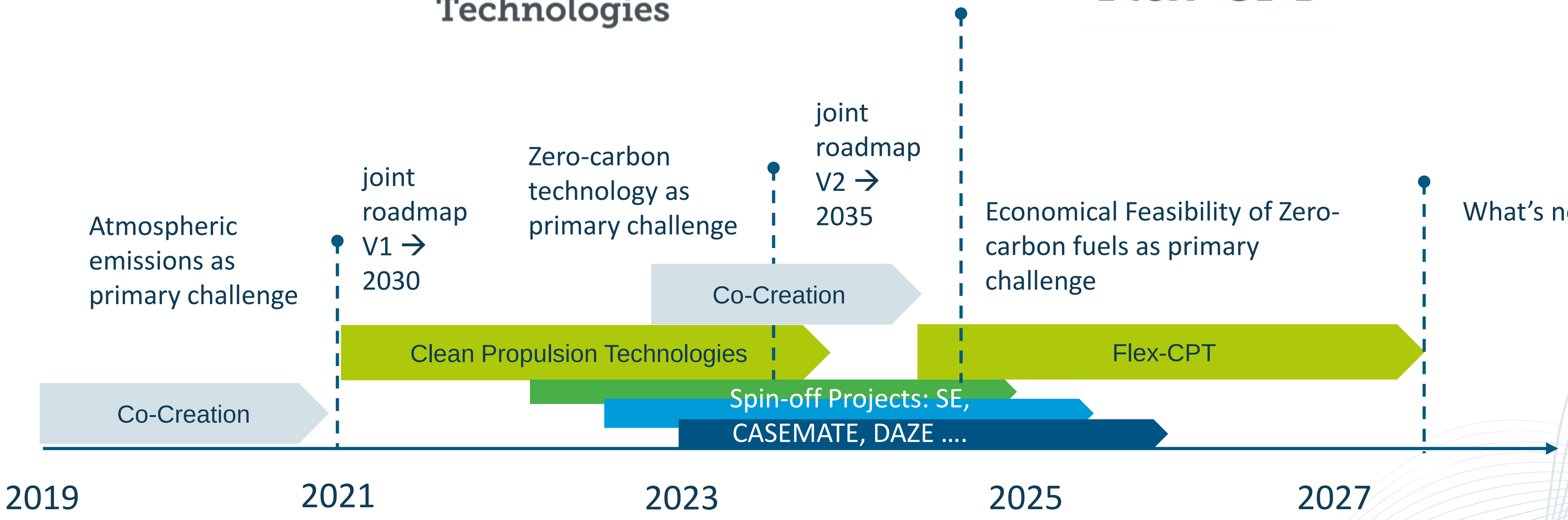
Clean Propulsion Technologies

Cutting-edge rapid prototyping methods

Innovative hardware and control

Flex-CPT

…to secure an economically stable, zero-emission business for the Finnish powertrain industry, by jointly handling the immense complexity problem of a fuel-diversified future.



Flexible Clean Propulsion Technologies

Flex-CPT - The critical mass for co-innovation in propulsion!

Flexible Clean Propulsion Technologies

CO-FUNDED BY BUSINESS FINLAND

Company Projects

WÄRTSILÄ
AGCO POWER
MEYER TURKU
PROVENTIA

Public Project

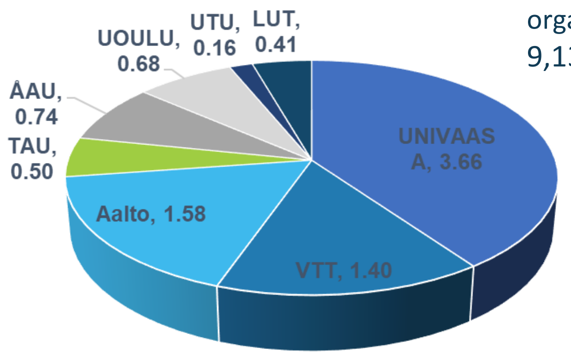
Vaasan yliopisto / University of Vaasa
Aalto University
Åbo Akademi
LUT University
VTT
University of Oulu
University of Turku
Tampereen yliopisto / Tampere University

Supporting Project Partners

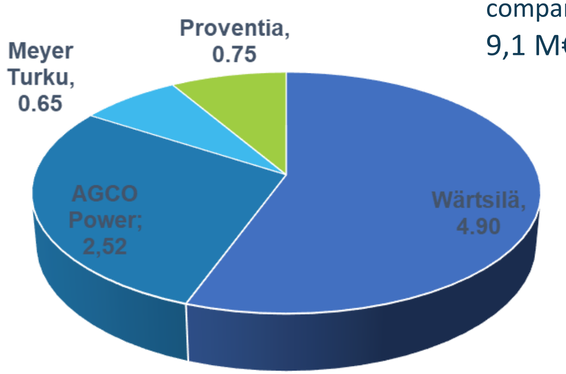
rexroth – A Bosch Company
NESTE
Lumikko
hycamite
MERIAURA

Lund University, Arizona State University, Harbin University of Technology, Politechnika Lubelska (Lublin University of Technology), Hitit Üniversitesi, IEA-AMF Technology Collaboration Programme on Advanced Motor Fuels, KAIST, Politecnico di Torino, KIT Karlsruher Institut für Technologie, University of Cyprus, Université Claude Bernard Lyon 1, UiA University of Agder

research organizations 9,13 M€



companies 9,1 M€



Flex-CPT Total Budget: 18,23 M€

CPT and spin-offs : > 21 M€

Flexible Clean Propulsion Technologies

Clean Propulsion Technologies (CPT) …

.... **Delivered:**

- 28 innovative solutions in powertrain control/development
- encapsulated in 4 ground-braking technology platforms

DF RCCI

WARTSILA RCCI technology
Pilot (8V31DF) on M/V
Aurora Bothnia

AGCO CORE50
E-Hydrogen
Engine of the year
AGRITECHNICA 2023

CC-
SCR

Proventia Close-Coupled
SCR Aftertreatment For
EPA Tier 5 Applications
(CARB)

S-Wille Electro-hydraulic
Hybrid architecture

Flexible Clean
Propulsion
Technologies

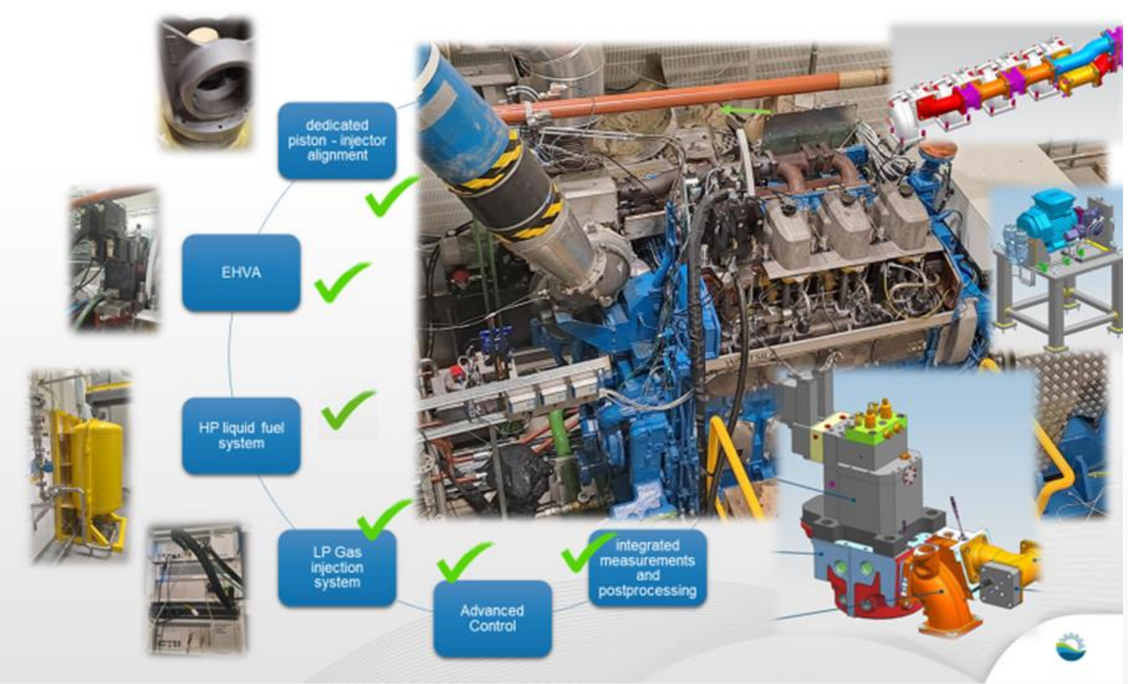


Fig. 1. Cutting-Edge RCCI research platform, developed in CPT, at Uni-Vaasa Energy Labs

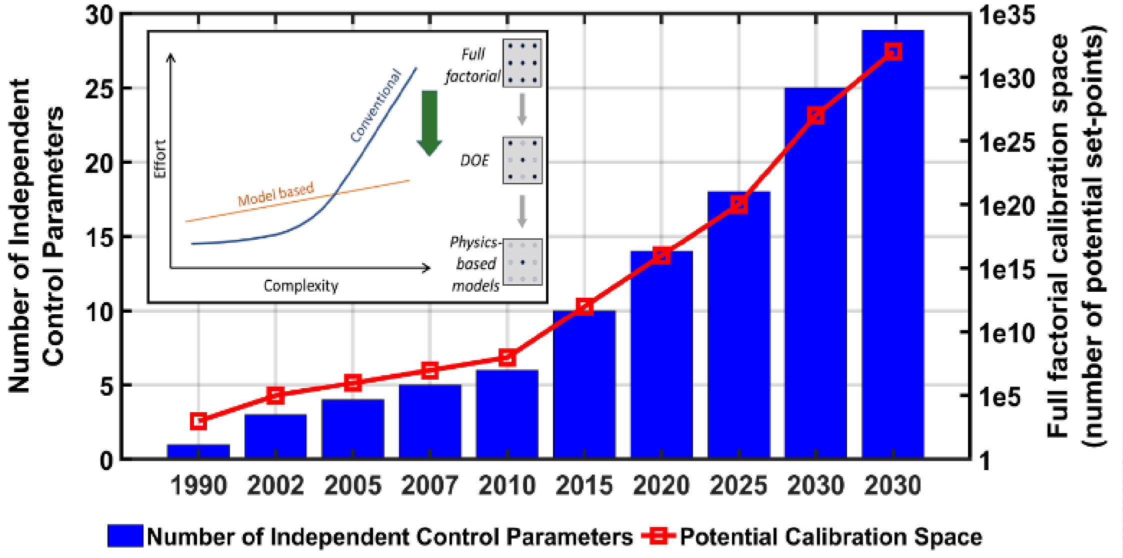
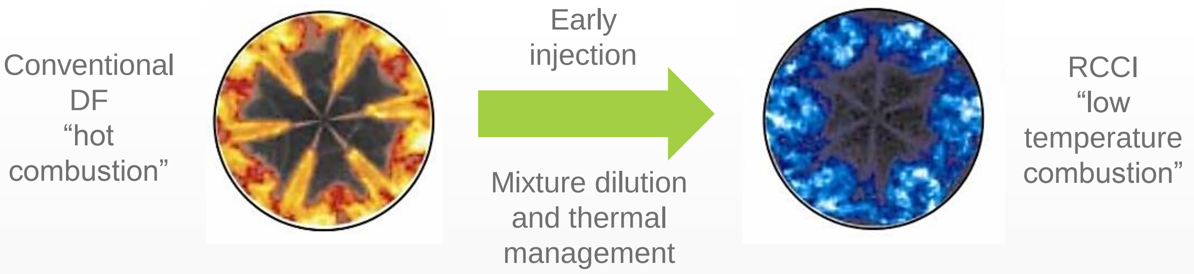


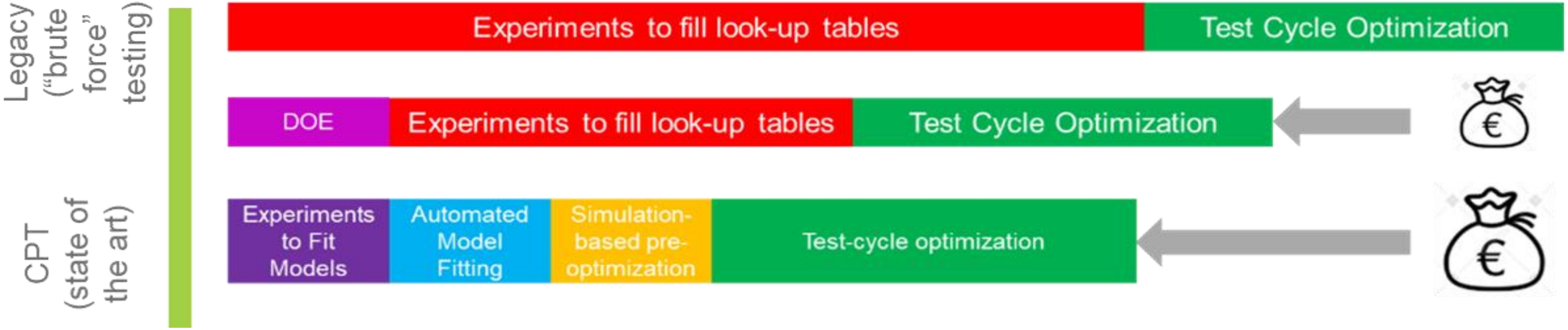
Fig. 2. RCCI calibration challenge; 14 independent control parameters = 10^17 combinations to cover the calibration space = 3Milion years by conventional testing

Reactivity - Controlled Compression Ignition



- ❑ Superior Efficiency (up to 55% Indicated)
- ❑ Ultra-Low emissions
- ❑ Wide control authority with VVA= flexible accommodation of various fuel options
- ❑ Very large calibration space (requires model-based development)
- ❑ None-Linear, highly dynamic control response (requires predictive/adaptive controllers)
- ❑ Starting point TRL3 → high-risk / high-gain
- ❑ Target TRL7 in 3 years

Feasibility of CPT/FLEX-CPT model-based development methods



Kakoee, A.; Mikulski, M.; Vasudev, A.; Axelsson, M.; Hyvönen, J.; Salahi, M.M.; Mahmoudzadeh Andwari, A. Start of Injection Influence on In-Cylinder Fuel Distribution, Engine Performance and Emission Characteristic in a RCCI Marine Engine. *Energies* 2024; https://doi.org/10.3390/en1710237.

Kakoee, A.; Vasudev, A.; Smulter, B.; Hyvonen, J.; Mikulski, M. A predictive 1D modeling framework for reactivity-controlled compression ignition engines, via a chemistry-based, multizone combustion object. SAE Technical Paper 2023, 2023-24-0001; https://doi.org/10.4271/2023-24-0001.

Kakoee, A.; Hunicz, J.; Mikulski, M. Integrated 1D simulation of aftertreatment system and chemistry-based multizone RCCI combustion for optimal performance with methane oxidation catalyst. *J Mar Sci Eng*. 2024, 12, 594; https://doi.org/10.3390/jmse12040594.

Vasudev, A.; Cafari, A.; Axelsson, M.; Mikulski, M. et al. Towards Next Generation Control-Oriented Thermo-Kinetic Model for Reactivity Controlled Compression Ignition Marine Engines. SAE Technical Paper 2022, 2022-01-1033; https://doi.org/10.4271/2022-01-1033.

Vasudev, A.; Mikulski, M.; Ramanujam Balakrishnan, P.; Storm, X.; Hunicz, J. Thermo-kinetic multi-zone modelling of low temperature combustion engines. *Prog Energy Combust. Sci.* 2022, 91, 100998; https://doi.org/10.1016/j.pecs.2022.100998.

Vasudev, A.; Mikulski, M.; Hyvönen, J. Effects of H2 admixture on RCCI combustion dual-fuel marine engines: A model-based study. *Int J Hydrog Energy* -IEEES-14: Special Issue 2024, (in-print).

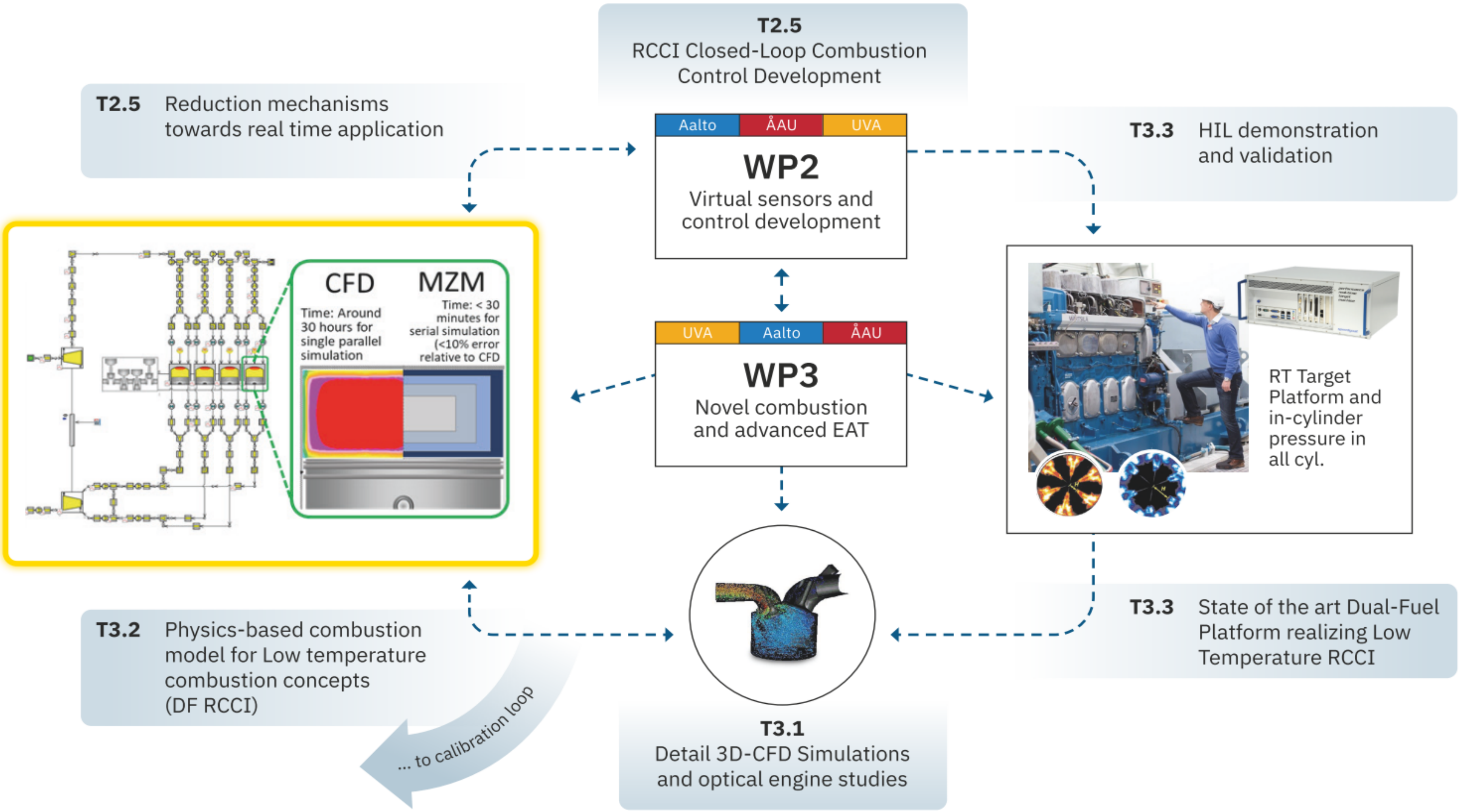
Vasudev, A.; Kakoee, A.; Axelsson, M.; Maleki Almani, H.; Hyvonen, J.; Mikulski, M. Advancing autonomy of chemical kinetics based multizone models for reactivity controlled compression ignition engines. *Energy Convers Manag*. 2024, 312, 118562; https://doi.org/10.1016/j.enconman.2024.118562.

Vasudev, A.; Mikulski, M.; Hyvönen, J. Effects of H2 admixture on RCCI combustion dual-fuel marine engines: A model-based study. Inter. Journal of Hydrogen Energy

Selected publications related to model-based RCCI platform development in CPT – full list of papers see https://cleanpropulsion.org/

Flexible Clean Propulsion Technologies

CPT Methods and toolchains - Model-Based control design



(Semi) Single Cylinder Research Engines:
200mm bore
and 310mm
Full-Flexible VVA

T3.2 In-House Kinetic MZM coupled with GT-suite

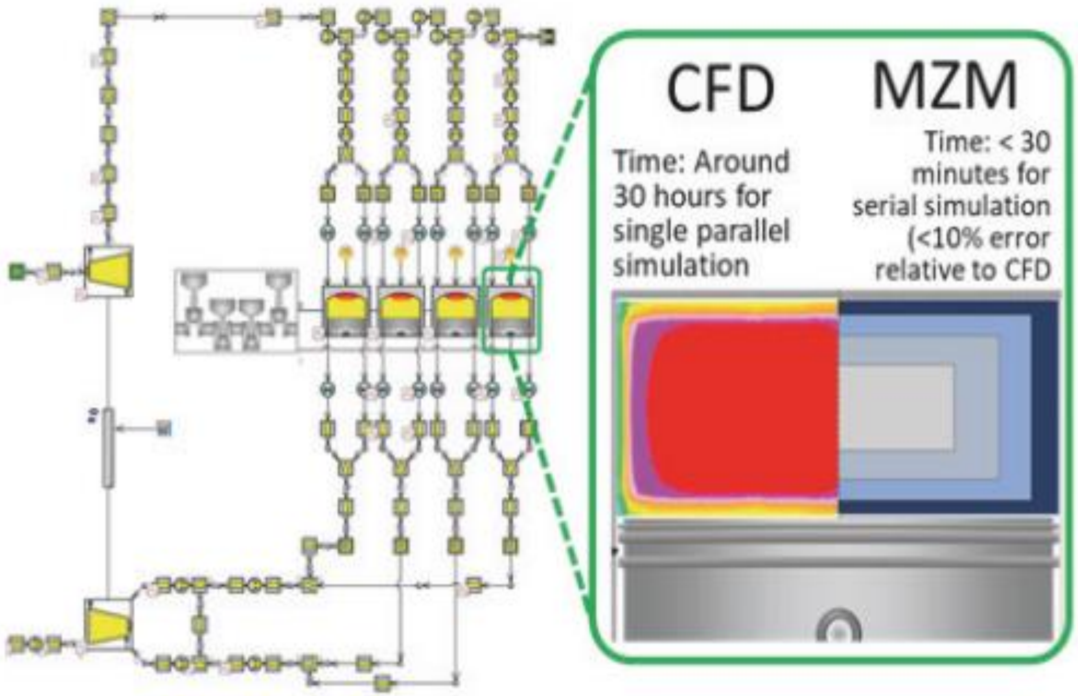


Table 2: Operating points from the SCRE for model calibration.

Case	Load [%]	λ [–]	BR [pp]	SOE [CAobTDC]	T_{in} [K]	P_{in} [bar]
A (16191)	11	ref + 1.8	ref – 41.9	ref + 65	ref	ref + 0.5
B (16190)	25	ref + 1.0	ref – 10.9	ref + 65	ref	ref + 1.3
C (16253)	50	ref + 0.5	ref – 1.9	ref + 50	ref – 5	ref + 3.7
D (16216)	50	ref + 0.8	ref – 2.4	ref + 65	ref – 5	ref + 3.5
E (16219)	50	ref + 0.8	ref + 0.9	ref + 26	ref – 5	ref + 3.8
F (16255)	83	ref + 0.1	ref – 0.9	ref + 50	ref – 7	ref + 6.3

Table 2: SCRE Engine technical data

Engine	Wartsila MONO (31DF SCRE)
Displacement & nominal speed	32.45 l / 720 rpm
Stroke/Bore	1.39
Air system	External air compressor with air temperature and pressure con- trol (up to 10 bar)
High-reactivity fuel system	Common rail 2.0 with twin needle injector; and multi-injection capability
Low-reactivity fuel system	Low-pressure, multi-point, upstream of the intake valves
Valvetrain	four valves with swirl + tumble ports; variable intake valve closure (VIC); fixed exhaust valve opening (EVO)
Emission system	Horiba Mexa-One (NO_X, CO, THC, CO_2, O_2) AVL415S (FSN-soot)
Indicative system	AVL Indicom, cylinder pressure transducer Kistler 6124A, 300 bar range, 30pC/bar sensitivity.
Engine control	SpeedGoat™ Rapid prototyping platform
Test fuels	ISO 8217 compliant LFO / LNG (MN=80)

T3.2 In-House Kinetic MZM coupled with GT-suite

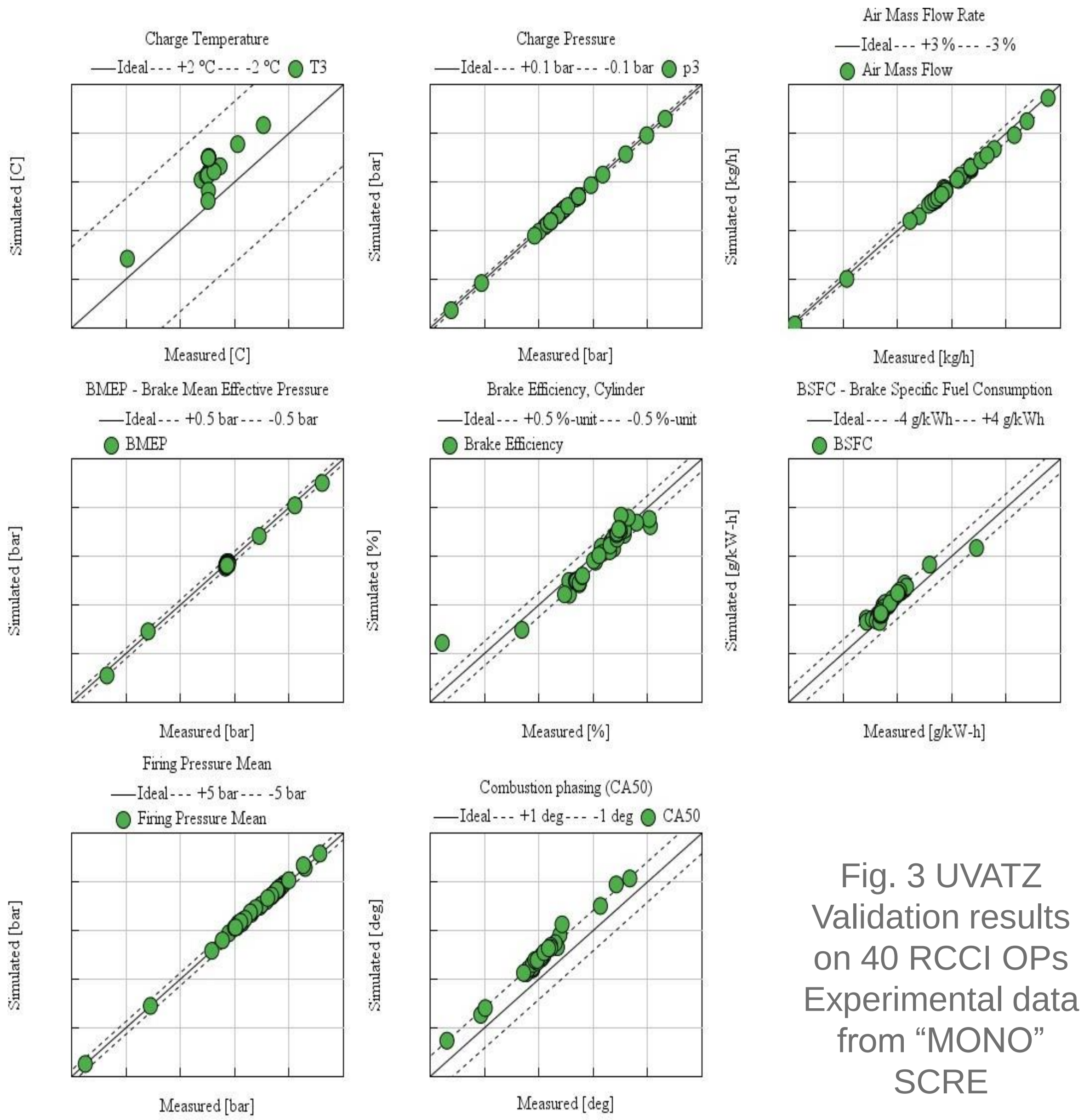


Fig. 3 UVATZ Validation results on 40 RCCI OPs Experimental data from “MONO” SCRE

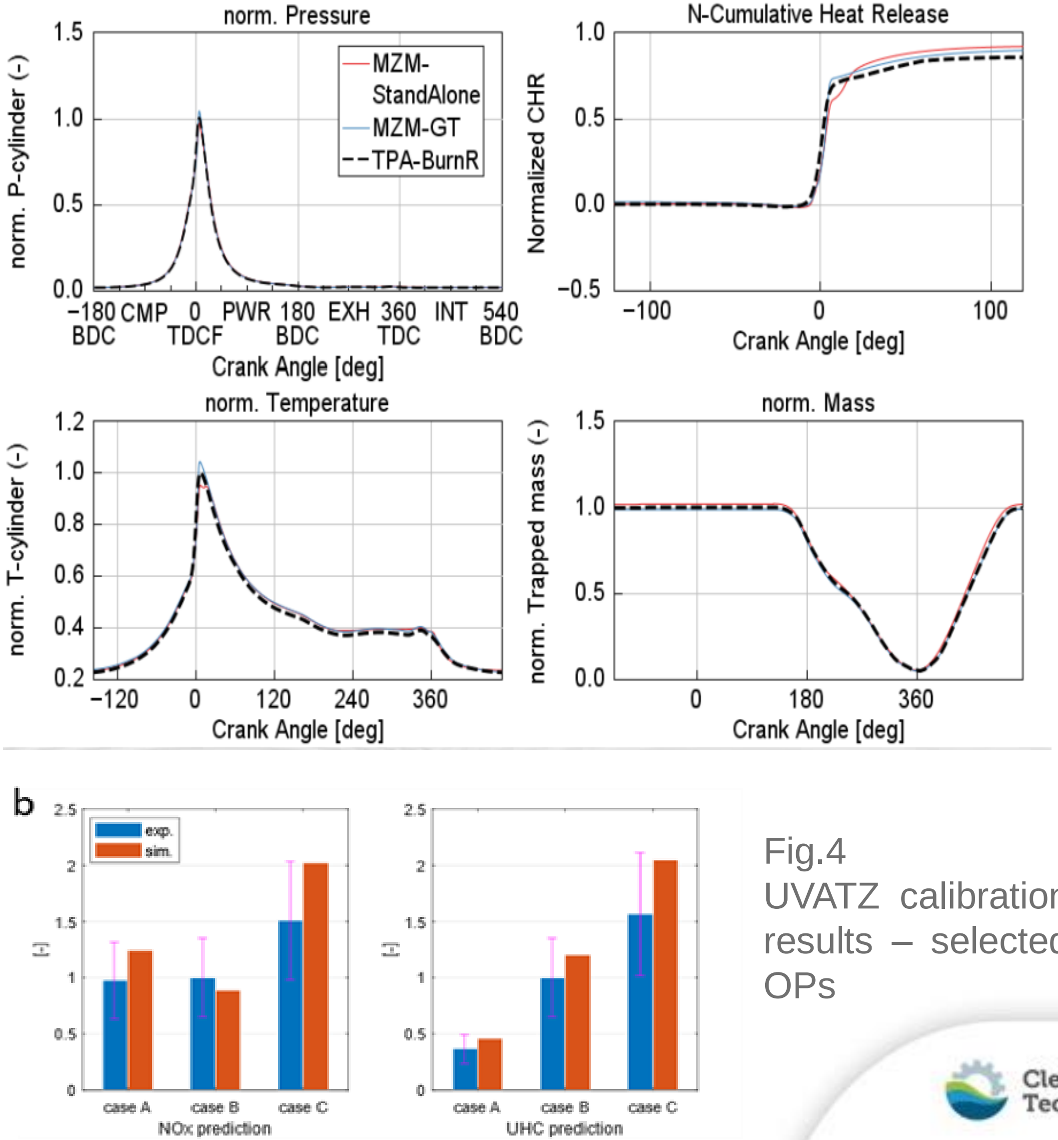
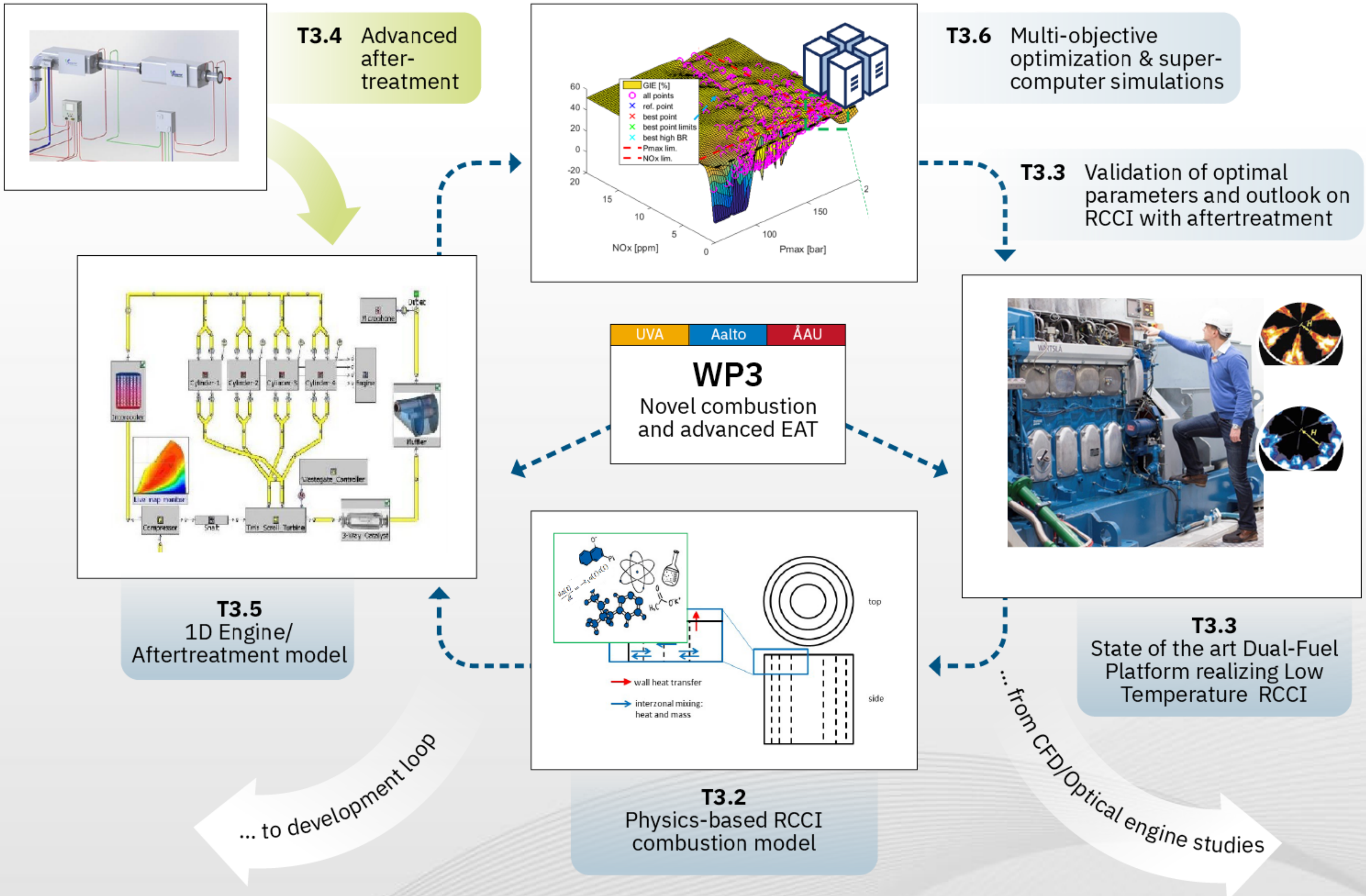


Fig.4
UVATZ calibration results – selected OPs

Clean Propulsion Technologies

CPT Methods and toolchains - Model-Based calibration



Multi-Cylinder Wartsila 8V31 Next-DF (partial VVA)

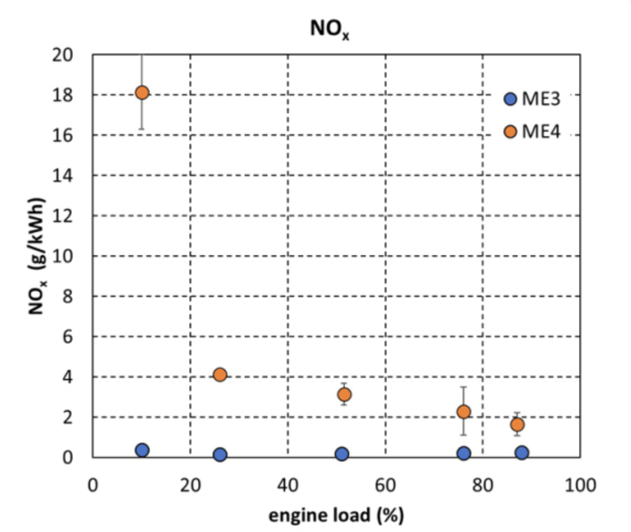
3 years to test-bed validation

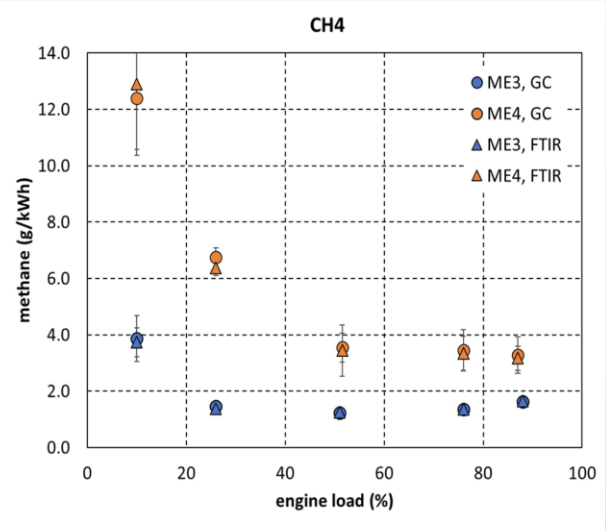
(Semi) Single Cylinder Research Engines:
200mm bore
and 310mm
Full-Flexible VVA

Clean Propulsion Technologies

New version of the Wärtsilä 31DF engine reduces methane emissions by an additional 41% on average, when compared to previous market best

Wärtsilä Corporation, Trade press release 1 November 2023 at 11:00 UTC+2





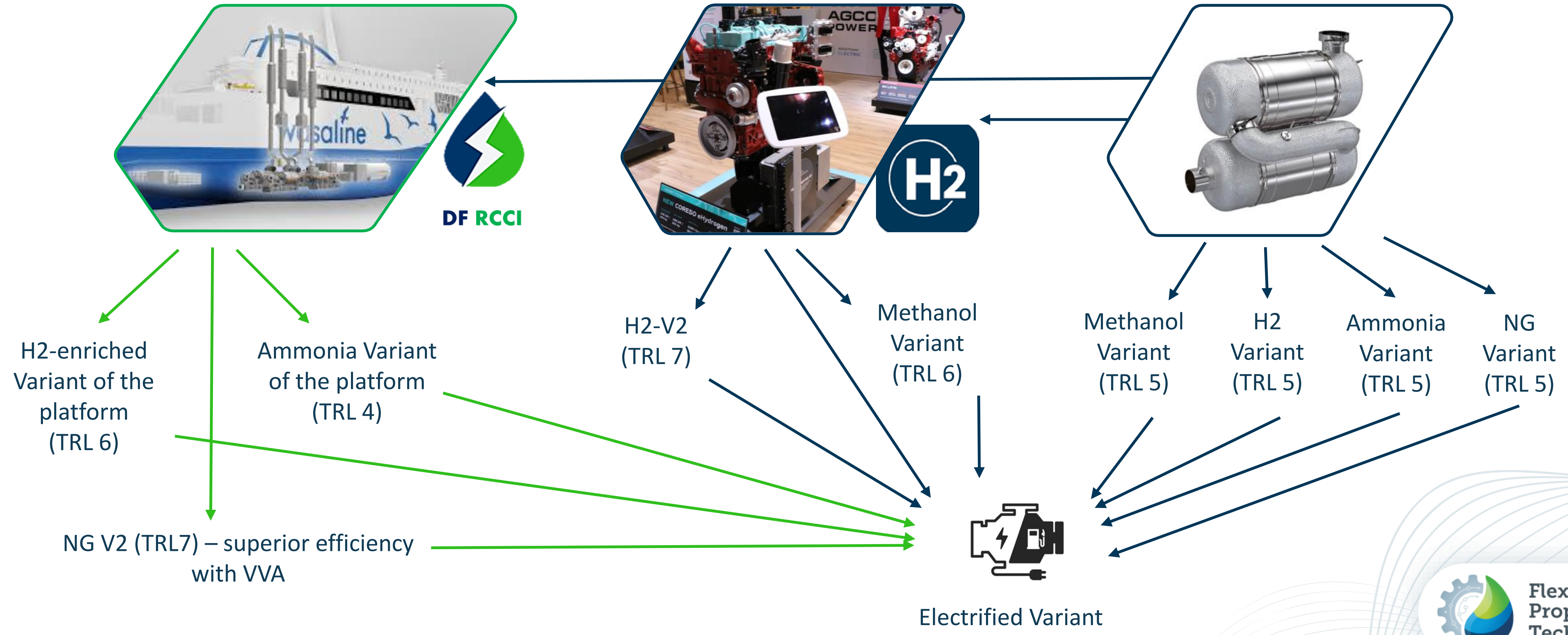
RCCI as enabler for multi-fuelling

- GHG Reduction target of 20% compared to state of the art dual fuel is achieved!
- NOx and PM are below emission measurement accuracy!
- RCCI provides wider calibration margins than conventional DF
- Advanced RCCI hardware, control features, and rapid prototyping measures developed in CPT are the enablers for managing the multi-fuel complexity challenge!
- Towards 0-carbon fuels in a flexible, economically feasible manner in Flex-CPT

Emissions from Wärtsilä 8V31 DF on board M/V Aurora Botnia, piloting RCCI technology (main engine 3, ME3) with a conventional dual-fuel combustion (main engine 4, ME4).
Plots reproduced from CPT publications [26], and [29].

Flex-CPT

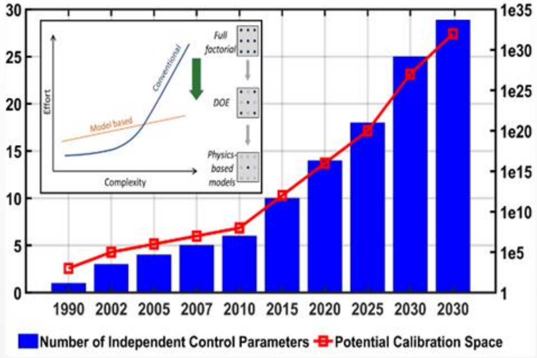
- based on cutting edge platforms from CPT…
- …. creates 28 new product-market combinations (PMCs) related to different fuels



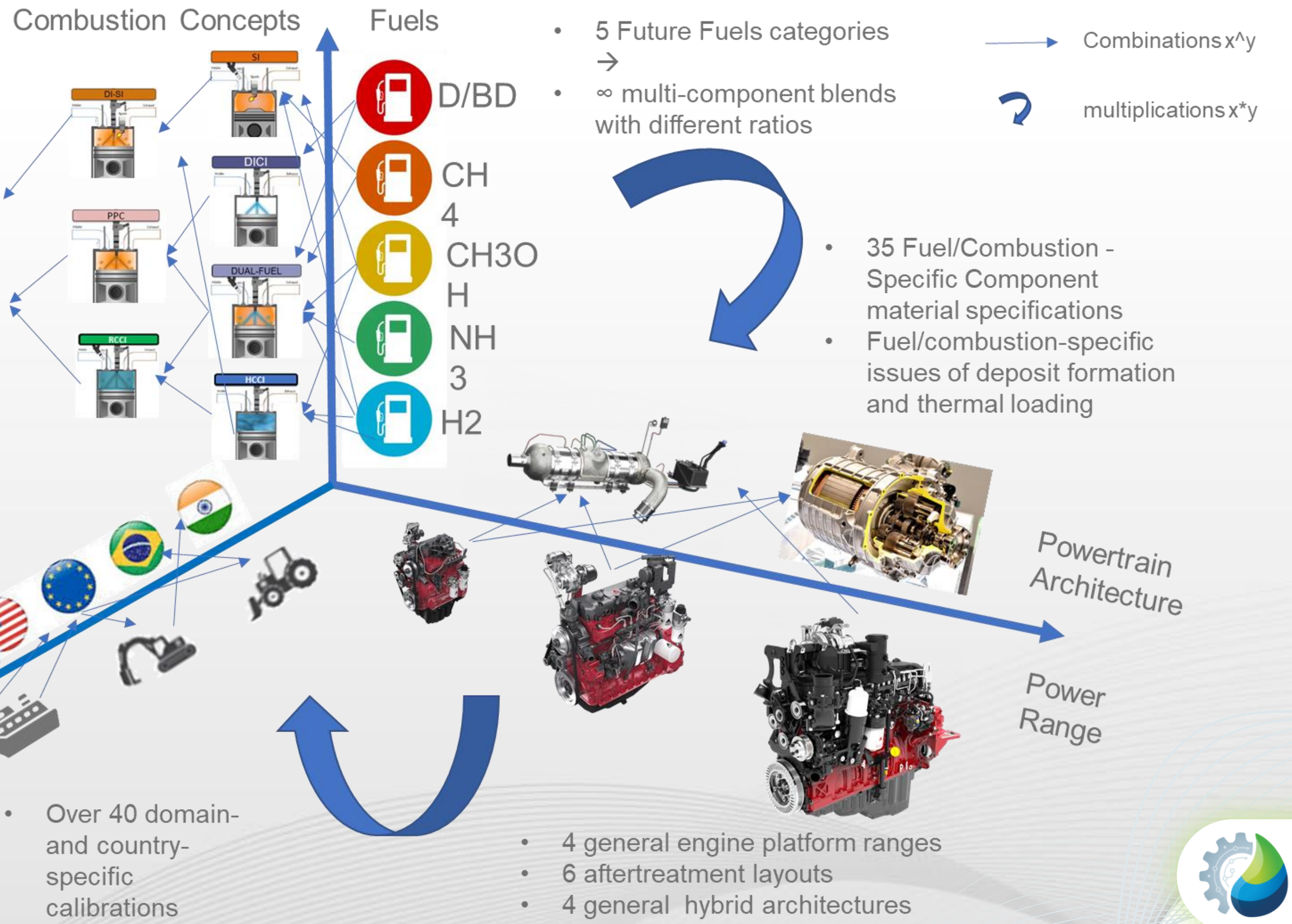
Flexible Clean Propulsion Technologies

The Challenge - Calibration Complexity and Platform Versatility

- For each fuel….
- 7 Possible combustion concepts
- Up to 14 independent control parameters each



- 5 years of development per calibration
- Already with rapid prototyping



- 5 Future Fuels categories →
- ∞ multi-component blends with different ratios

- 35 Fuel/Combustion - Specific Component material specifications
- Fuel/combustion-specific issues of deposit formation and thermal loading

- Over 40 domain- and country-specific calibrations

- 4 general engine platform ranges
- 6 aftertreatment layouts
- 4 general hybrid architectures

Flexible Clean Propulsion Technologies

Objectives

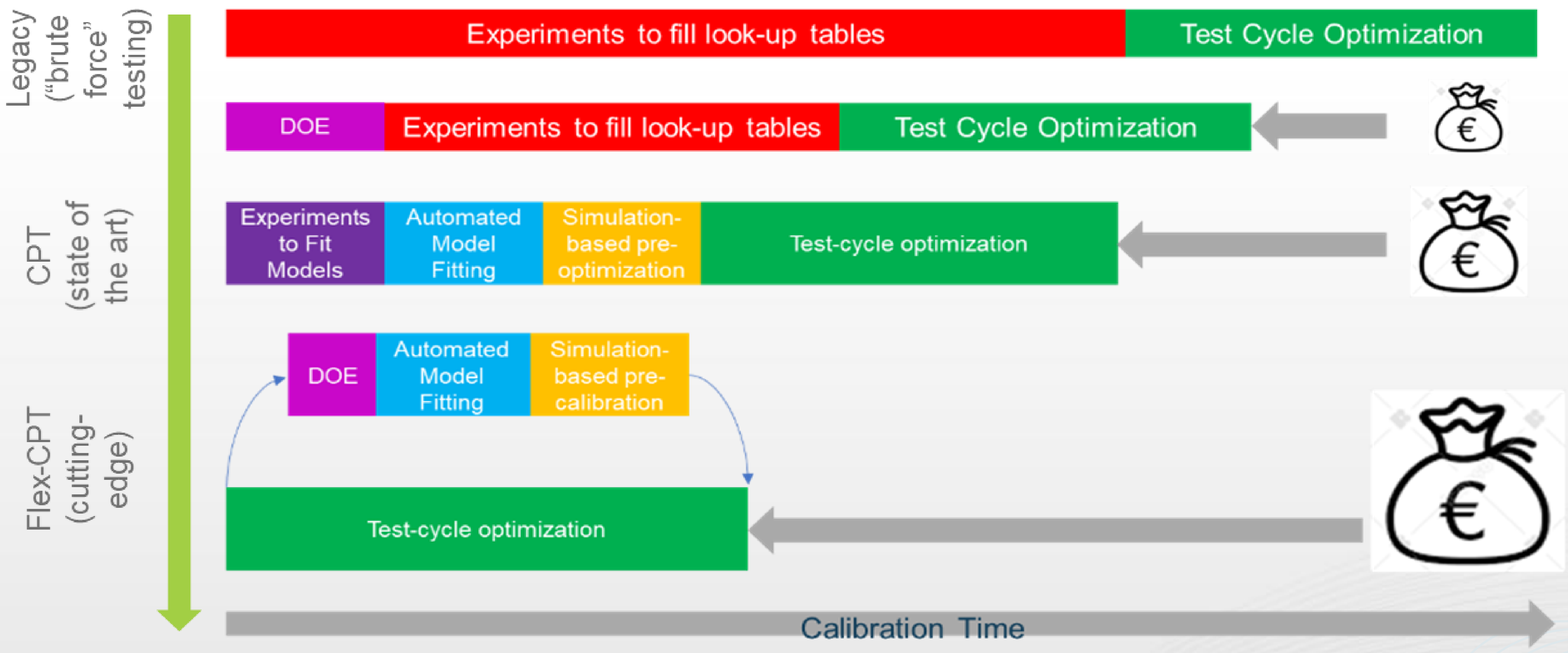
Flex-CPT WP1: Multi-fuel Marine Engines

- **O1:** Increase the level of maturity in multi-fuel RCCI through excellence in experimental research towards H2 blending (flexible up to 80% target).

- **O2:** Build model-based control/optimization functionalities that enable fuel flexibility with large-scale variations in fuel composition.

- **O3:** Demonstrate emission-compliant multi-fuel RCCI variant with Stage V emission targets across the full envelope.

Feasibility of CPT/FLEX-CPT model-based development methods



Flexible Clean Propulsion Technologies

Want to know More:

https://cleanpropulsion.org/

- Research Impact:
  - Over 45 per-reviewed scientific articles and thesis’s
  - Exposure on 15 international conferences
- Societal Impact:
  - Over 30 times covered by international media
  - Over 150 stories on project social media channels

Flexible Clean Propulsion Technologies

Thank you for your excellent effort!

Prof. Maciej Mikulski

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Co-funded by BUSINESS FINLAND

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